

SUMMARY OF MARTIAN DUST FILTERING CHALLENGES AND CURRENT FILTER DEVELOPMENT

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Introduction: Traditional air particulate filtering in manned spaceflight (Apollo, Shuttle, ISS, etc.) has used cleanable or replaceable catch filters such as screens and High-Efficiency Particulate Arrestance (HEPA) filters. However, the human mission to Mars architecture will require a new approach. It is Martian dust that is the particulate of concern but the need also applies to particulates generated by crew. The Mars Exploration Program Analysis Group (MEPAG) highlighted this concern in its *Mars Science, Goals, Objectives, Investigations and Priorities* document [7], by saying specifically that one high priority investigation will be to “Test ISRU atmospheric processing systems to measure resilience with respect to dust and other environmental challenge performance parameters that are critical to the design of a full-scale system.” By stating this as high priority the MEPAG is acknowledging that developing and adequately verifying this capability is critical to success of a human mission to Mars. This architecture will require filtering capabilities that are highly reliable, will not restrict the flow path with clogging, and require little to no maintenance. This paper will summarize why this is the case, the general requirements for developing the technology, and the status of the progress made in this area.

Filtering Applications: The surface equipment required for human missions to Mars drive the need for dust filtering in a number of applications. Some will have to operate in the low pressure CO₂ Martian environment and some will operate in pressurized habitable volumes. The following is a summary of the systems which, if implemented in the human mission to Mars architecture, will need the capability to filter out Martian dust.

In-Situ Fuel Production from Martian Air. In most mission architectures fuel for an ascent vehicle is generated before the crew ever arrives. The pre-positioned In Situ Resource Utilization (ISRU) system must operate for years without the need of maintenance. Air ingested and put through chemical processing must be as clean as possible or the system will be fouled, leading to reduced performance at best and total failure at worst. The filter must be 100% reliable either in design, fault tolerance or redundancy since no one is there to empty, clean or replace it.

Habitat O₂ Production from Martian Air. Similar to the ISRU fuel production system, but presumably part of the habitat, this system shares the same challenge. Here, however, maintenance could be an option.

Airlock Pump Down Systems. The habitat will have an airlock even if suit ports are used for EVA in order to bring suits or machinery for maintenance and to bring supplies and equipment into the habitat. This system may include a pumping unit to remove the thin, dust laden CO₂ before repressurizing with habitat air. The dust in the Martian air will need to be filtered out to prevent degradation of the pumping system.

Habitat and Pressurized Rover ECLSS. Mitigation techniques will be implemented to minimize the amount of Martian dust introduced into the habitat and pressurized rover environments but it will not be 100% precluded. This issue is of specific concern due to the potential of crew health hazards related to the constituents in the dust. If traditional HEPA filters are used for the cabin a reliable prefilter for dust may be needed since the loading rate is unknown. It will not be practical to bring a large number of replacement cabin filters “just in case” the rate is high. Furthermore, since dust may settle or cling to the floor or other surfaces in the habitat it may be necessary to provide dedicated filter systems near the likely points of entry

Derived Filter Design Requirements: The challenge of addressing the filtering needs becomes evident when attempting to derive the high level requirements for such a system. Loading rates are unknown and will vary, especially for systems that operate in the Martian atmospheric environment. Reliability, as mentioned earlier is also a key driving requirement. What follows is a first order summary of the key requirements that must be established:

Reliability. As mentioned, for the ISRU fuel production system the filter Mean Time Between Failures (MTBF) must be longer than the expected operating time before crew arrives. This period has been described in terms of years. The remaining applications have the potential of being repaired by the crew.

Maintainability. Maintenance capabilities must be carefully considered due to limited mass and volume considerations. Additionally, designing the capability for crew maintenance can increase mass and volume of the habitat systems and limit design options. In some applications it will be a necessary penalty, but each circumstance will be scrutinized to ensure it is necessary.

Volume, Power and Mass. Always drivers for every spacecraft, these parameters will need to be minimized. Design options that include dedicated fans, pumps and electric fields all require more power.

Load Rate Capability. The rate at which the dust particulates are introduced is a key design driver. The system must maintain a minimum removal efficiency at the maximum expected load rate or risk break through. This rate is not well understood for the external systems and subject to the variability of exploration operations for the internal systems. One approach taken by researchers has been to use optical data from the MER missions which found dust concentrations of about 6 particles/cm³ [6]. However, this rate will vary based on the presence of winds and will increase greatly in the presence of a dust storm. One estimate has put the density of dust particles in a dust devil at about 10 particles/cm³ [3][4]. The flowrate of this dust laden air depends on the design of the ISRU system, but 88 g/h has been used in development testing [2].

Load Characteristics. Robotic missions have gathered a fair amount of data about the Martian dust and simulants have been generated for years. Landis, et al [5] have determined a size distribution between 1 μ m and 40 μ m for the bulk of the airborne particulate.

Working Environment. As noted by Agui [1] and Calle, et al [2], the thin CO₂ Martian air presents a challenge to traditional catch filter and electrostatic precipitator (ESP) technology. Additionally the temperature swings must also be taken into account.

Not surprisingly the test and verification process to prove that the filter technology meets the derived requirements described above will be a challenge, especially considering that all tests will be done using Mars dust simulant and not the real thing. A development program will need to plan significant amounts of time to test reliability, loading rates and the environmental conditions.

Filter Design Progress: The need for filters to meet the mission architecture has not gone unnoticed in the research community. Several efforts have been underway led by NASA KSC and GRC.

At the NASA GRC a unique testing platform was built in the form of a closed-loop air flow system to test filter media. This system has the capability to maintain a Mars-like environment and introduce particulate and detect how much may have made it past the filter [1]. This facility has already been used to test HEPA filter media in Martian conditions. As of a 2015 report the system needed some improvements to its laser sheet particle detection system in order to better assess filter performance in support of future filter development testing [1].

At NASA KSC Calle et al [2] have tested an Electrostatic Precipitator (ESP) style filter using Mars simulant dust in a Martian simulated environment with some success. There are challenges remaining in this design as it was expected to have much less effective-

ness than initial tests showed which needs to be better understood. Also led by Kennedy Space Center, the Blazetech Corporation has been developing a two stage filtration device, presumably based on the earlier ESP testing, intended for ISRU system use. Their plans are to mature the design to TRL 6 in 2017. [9]

The development of these systems and test facilities over the past few years is a promising and well timed activity. The maturation of appropriate filter systems must be done now to support missions to Mars in the 2030's as outlined in the latest NASA budget proposal. However, a specific mission architecture still needs to be defined so that detail requirements can be derived. Without knowledge of packaging, mass and power limitations the prototype filter systems being developed now may be faced with a redesign, negating some of the work and testing already done.

The Mars 2020 rover payload Mars Atmosphere Resource Verification InSitu (MARVIN) will provide a wealth of knowledge directly applicable to the human mission architecture. Within this system the Atmosphere and Dust Measurement and Filtration (ADMF) subsystem is being designed to test filtration methods, as well as the absence of filtration, and observe the results in the ISRU system performance. The baseline design will test a HEPA filter with a bypass line included to test the effects of unfiltered Martian air. An option is being considered for the bypass line to include an ESP filter that can be turned on and off. Also, of great interest is the plan for the ADMF to include sensor technology to measure particle sizes and quantities. The results of the MARVIN payload will enable future designers to more fully define the requirements discussed earlier. [8]

Summary: The Martian dust filter in an ISRU fuel production plant is its Achilles Heel. A clogging or other failure of the filter during the long unmanned fuel production phase would cause an abort of the human mission due to fouling or cascading failure of the fuel producing process. Additionally, filter devices will need to be included in several other surface systems including habitat and rover ECLS. While initial technology developments are promising, much work has yet to be done to address all the driving requirements of dust filtering. As seen in this paper, these requirements are still vague in key areas. Furthermore, an adequate test program needs to be developed to ensure the design is verified and validated. Adequately resolving the airborne dust concerns is just one piece of the puzzle which must be assembled for a successful human mission to Mars. As with other challenges, the sooner we converge on a solution the better.

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